FIELD DEMONSTRATION OF ENHANCED SORBENT INJECTION FOR MERCURY CONTROL

QUARTERLY TECHNICAL PROGRESS REPORT

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AC	activated carbon
BOP	balance of plant
CMM	Continuous mercury measurement
DJ3	PacifiCorp's Dave Johnston Unit 3
DOE	U.S. Department of Energy
EERC	Energy and Environmental Research Center
ESP	electrostatic precipitator
LOS/LOS1	Basin Electric's Leland Olds Unit 1
NETL	National Energy Technology Laboratory
NDIC	North Dakota Industrial Commission
PRB	Powder River Basin
SCA	specific collection area

Executive Summary

ALSTOM Power Inc., Power Plant Laboratories (ALSTOM-PPL) is currently carrying out a consortium-based, DOE-NETL program to demonstrate Mer-Cure™ technology, ALSTOM-PPL's novel and oxidation-based mercury control technology in coal-fired boilers. In the program, ALSTOM-PPL teams up with the University of North Dakota – Energy and Environmental Research Center (EERC), PacifiCorp, Basin Electric Power Cooperative (Basin Electric), Reliant Energy, North Dakota Industrial Commission (NDIC), and Minnkota Power.

The full-scale demonstration program consists of three seven-week long test campaigns in three independent host sites firing a wide range of coal ranks. These host sites include PacifiCorp's 240-MW_e Dave Johnston Unit 3 burning a Powder River Basin (PRB) coal, Basin Electric's 220-MW_e Leland Olds Unit 1 burning a North Dakota lignite, and Reliant Energy's 170-MW_e Portland Unit 1 burning an Eastern bituminous coal. These boilers are all equipped with an electrostatic precipitator (ESP).

In Mer-Cure™ technology, a small amount of sorbent (Mer-Clean™) is injected into a flue gas stream environment where the gaseous elemental mercury oxidation and removal is favorable. The sorbents are prepared with chemical additives that promote oxidation and capture of elemental mercury. The Mer-Cure™ mercury control technology offers a great opportunity for utility companies to control mercury in the most cost-effective manner while minimizing any balance-of-plant impact.

ALSTOM-PPL has made significant accomplishments in demonstrating the performance of Mer-Cure™ mercury control technology during the performance period. Highlights of the accomplishments are:

- Completed parametric testing at Basin Electric's Leland Olds Station 1;
- Completed long-term testing at Basin Electric's Leland Olds Station 1;
- Disassembled the Mer-Cure™ system and shipped it back to Windsor site;
- Completed reduction of PacifiCorp test data; and
- Held additional site meetings in preparation for the upcoming Reliant Energy test campaign.

Analysis of data from PacifiCorp Dave Johnston testing clearly demonstrate that ALSTOM-PPL's Mer-Cure™ system can achieve 90% removal of uncontrolled gaseous mercury at 0.85 lb/MMacf. Preliminary data from Basin Electric test campaign supports similar performance of Mer-Cure™ system. In the next performance period, ALSTOM-PPL will complete Basin Electric data analysis and continue preparation for Reliant Energy test campaign. Laboratory-scale testing will also be carried out in a test setup while burning PacifiCorp and Basin Electric fuels. The project is being executed on schedule and budget.

INTRODUCTION

The overall objective of the DOE/NETL-sponsored project is to perform full-scale demonstration of Mer-Cure™ technology in three coal-fired boilers burning coals of various ranks. These host sites include PacifiCorp's 240-MW_e Dave Johnston Unit 3 (DJ3) burning a PRB coal, Basin Electric's 220-MW_e Leland Olds Unit 1 (LO1) burning a North Dakota lignite, and Reliant Energy's 170-MW_e Portland Unit 1 burning an Eastern bituminous coal. These boilers are all equipped with an ESP (Table 1).

In the program, ALSTOM-PPL will demonstrate that greater than 70% of gaseous mercury in the flue gas can be captured by injection of enhanced sorbent at a feed rate significantly lower than required by standard activated carbon. ALSTOM-PPL will also collect performance data that can be used to accelerate commercialization of our mercury control technology.

Mer-Cure™ technology applied to coal-fired power generation has the potential to be a cost-effective mercury control technology for the entire range of coals (bituminous, sub-bituminous, and lignite) and, in particular, the more challenging coals (for example, PRB and lignite coal). This control technology has low-capital costs (less than \$5/kW_e). It also requires a very small amount of additives for treatment, which results in low operating costs (0.5-0.75 mills/kWh) and minimal balance-of-plant (BOP) impact. As the technology is based on oxidation and adsorption of mercury, it is also applicable to all air pollution control configurations including wet scrubber and spray dryer-ESP/baghouse units. The main focus of the project, however, is coal-fired boilers with a cold-side ESP as the particulate control device, which represents 70% of the installed base in the United States.

The test program includes installation of equipment for the mercury control system, its operation under various firing conditions and measurement of elemental and oxidized mercury concentrations in the flue gas. The testing includes a one-week baseline mercury measurement and two weeks of parametric testing, followed by a four-week long-term testing. During the two-week parametric testing, the ALSTOM-PPL mercury control system will be operated with sorbents of several formulations at different sorbent injection rates to determine mercury oxidation and removal efficiencies. The optimum sorbent formulations and injection rates will be selected for the four-week testing to evaluate its long-term performance.

The EERC participates in the program by providing mercury measurement expertise. Continuous mercury measurement (CMM) will be carried out throughout the test period by installing CMM monitors before the injection location and after the ESP to provide both elemental and oxidized mercury concentrations in the stack gas. Ontario Hydro method will also be employed for some of the key test conditions to verify CMM data, to obtain mercury concentration and speciation measurements at ESP, and to ensure QA and QC of the measurements.

Table 1. Host site, coal and emission data for the field demonstration program

	PacifiCorp	Basin Electric	Reliant Energy
Unit	Dave Johnston 3	Leland Olds 1	Portland 1
Capacity (MW_e Gross)	240	220	172
Operation	Base-loaded	Base-loaded	Cycling
NO_x and SO_2 control	No low-NO_x Low sulfur coal	No low NO_x Low sulfur coal	Low-NO_x - LNCFS No sulfur control
Air Heater	Two Ljungstrom	Ljungstrom + Tubular	Ljungstrom
Particulate control (SCA in ft^2/kacfm)	CS-ESP (629)	CS-ESP (320)	CS-ESP (284)
Ash utilization	Sold for mine reclamation	Disposal	Disposal
Coal	Wyodak (PRB)	ND lignite	Bailey mine Pittsburgh seam coal
Higher Heating Value As-received(Btu/lb)	8,060	6617	12,800 – 13,100
S in coal (%)	0.94	0.63	2-2.5%
Ash %	10.09	9.86	6-8%
Cl in coal (ppmwd)-dry	<50		~1,500
Hg in coal (ppmwd)-dry	0.071	0.057-0.099	0.1-0.16
As-fired Hg level from Coal ($\mu g/Nm^3$)	7-9	6-10	10-16
Inlet Hg ($\mu g/Nm^3$)		T-7.9; PM-2.0; Ox-0.1; El-5.8- March '03	T-9.1; PM-0.9; Ox-7.4; El-0.8^+
Uncontrolled Hg Emission Stack (Hg^T, Hg^p, Hg^{ox}, Hg^{el}) ($\mu g/Nm^3$)	T: 5.55-8.71 PM: 0.01-0.04 El: 2.4-4.35 Ox: 3.1-4.35	T-7.8; PM-0.0; Ox-1.4; El-6.4- March '03	T-7.5; PM-0.0003; Ox-5.2; El-2.3^+ after ESP, before scrubber
Removal Efficiency		12-25% (ICR data)	36% for bituminous coals with CS-ESP
Carbon-in-ash		< 0.2%	10-12%
Flue gas temp (ESP Inlet)	330-360°F	375°F	277°F – full load

- Emissions data in the Table as of submission of the proposal to DOE/NETL

EXPERIMENTAL

Following are the major tasks being performed to achieve the project goals:

Task 1A. Design, Engineering and Fabrication of the Mer-Cure™ System for PacifiCorp's Dave Johnston Unit 3
Task 2A. Field Demonstration at PacifiCorp's Dave Johnston Unit 3

Task 1B. Design, Engineering and Fabrication of the Mer-Cure™ System for Basin Electric's Leland Olds Unit 1
Task 2B. Field Demonstration at Basin Electric's Leland Olds Unit 1

Task 1C. Design, Engineering and Fabrication of the Mer-Cure™ System for Reliant Energy's Portland Unit 1
Task 2C. Field Demonstration at Basin Electric's Leland Olds Unit 1

Task 3. Technology Transfer
Task 4. Program Management and Reporting.

During the current reporting period, analysis of data from PacifiCorp testing (Task 2A) has been completed. The field test campaign at Basin Electric's Leland Olds Station has been successfully carried out and sample/data analysis will follow (Task 2B). We have also started preparation for the upcoming Portland Unit 1 test campaign in March 2006 (Task 1C). Details of the project activities are described in this section.

Task 1A. Design, Engineering and Fabrication of the Mer-Cure™ System for PacifiCorp's Dave Johnston Unit 3

Task completed.

Task 2A. Field Demonstration at PacifiCorp's Dave Johnston Unit 3

All of data analysis except solid sample characterization has been completed during the current reporting period. Results of PacifiCorp testing are presented in the RESULTS AND DISCUSSION section of this report. The solid sample characterization study results will be reported in the next quarterly report.

Task 1B. Design, Engineering and Fabrication of Mer-Cure™ System for Basin Electric's Leland Olds Unit 1

Task completed.

Task 2B. Field Demonstration for Basin Electric Campaign

During the current performance period, one week of parametric testing was completed with several Mer-Clean™ sorbents at a range of injection rates, followed by 4 weeks of long-term testing, during which Mer-Cure™ system was operated under a couple of optimized testing conditions. Various plant data have been collected to evaluate the performance of Mer-Cure™ system. The mercury levels have been monitored both at the air heater inlet and the ESP outlet locations. Coal samples were collected from mills; ash samples were collected from ESP hoppers and the ash silo for characterization by independent DOE contractors. Gas analysis data were obtained from the plant data collection system. ESP operating parameters were also monitored.

Task 1C. Design, Engineering and Fabrication of Mer-Cure™ System for Reliant Energy's Portland Unit 1

In preparation for the design of the site-specific portion of the Mer-Cure™ system, CFD studies have been conducted for Portland Unit 1. Based on the studies, sorbent injection port number and location have been determined. Reliant Energy has completed installation of the injection ports. Details of the CFD studies are presented in the current quarterly report.

Task 2C. Field Demonstration for Reliant Energy's Portland Unit 1 Campaign

The task will be started in the next reporting period.

Task 3. Technology Transfer

No activities for the task.

Task 4. Project Management and Reporting

During the reporting period, ALSTOM-PPL had two site visits for site preparation meetings with Reliant Energy. In the meetings, the work breakdown was discussed in greater detail. Communications with Pennsylvania Department of Environmental Protection (PaDEP) were initiated in preparation for the upcoming test campaign. Documents were prepared and submitted for PaDEP approval. Potential location for the mobile unit as well as UND EERC's sampling shack locations has been identified. Requirements for UND EERC's sampling tasks were reviewed.

RESULTS AND DISCUSSION

PacifiCorp Dave Johnston Unit 3

During the current reporting period, reduction of the data collected from PacifiCorp's DJ3 test campaign in June – September 2005 has been carried out. The parametric testing results were presented in the previous quarterly report. Results for the long-term testing are presented in this section.

Table 2 lists the tasks carried out to complete the PacifiCorp test campaign and their associated timeline. Long-term testing had originally been planned to start in the 4th week of July; however, tube leaks at DJ3 and subsequent boiler start-up issues at the plant delayed the testing. The long-term testing was then started on 8/4/05 for continuous operation of Mer-Cure™ system over 30-day period.

Table 2. PacifiCorp Test Campaign Timeline

Tasks	Timeline
Baseline measurement	June 19 – 26, 2005
Parametric Testing	June 27 – July 2, 2005
Long-term testing	August 4 – September 4, 2005
System removal	September 6 – 9, 2005

Figure 1 shows a schematic diagram of the DJ3 plant layout showing various sampling locations. Coal samples were collected from mills and composite samples were prepared; ash samples were collected from ESP hoppers and the ash silo on a regular basis. The mercury levels were monitored using CMMs at the air heater inlet and the ESP outlet. The CMM readings were verified by conducting Ontario Hydro measurements several times from the same locations. Gas analysis data such as NOx, SOx and stack O_2 have been obtained from the plant data collection system. UND EERC crew conducted independent measurements of flue gas composition as part of the Ontario Hydro measurement efforts. The average stack temperature and stack O_2 during long-term testing were 335°F and 6.6% O_2, respectively. ESP operating parameters have been also monitored in order to evaluate the impact of sorbent injection on ESP operation.

Table 3 lists the average coal properties determined by analysis of coal composite samples. A total of ten (10) composite coal samples were collected and prepared from the four mills of DJ3 during test campaign. From these composite samples, the average mercury content of the coal and its standard deviation have been determined to be 0.08 μg/g dry coal, and 0.02 μg/g dry coal, respectively. The chlorine content of the coal was 50 ppm dry.

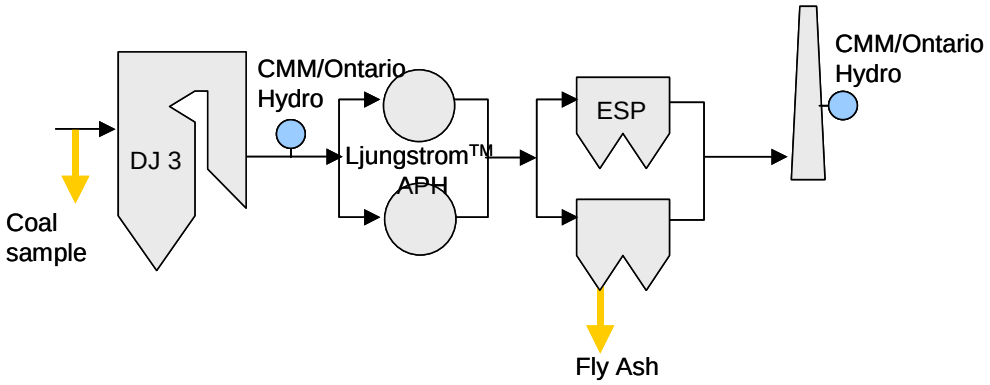

Figure 1. Sampling locations at PacifiCorp's DJ3

Table 3. PacifiCorp Coal Properties (Average)

Proximate analysis	As received	Dry basis
Total moisture (%)	29.50	N/A
Volatile matter (%)	30.75	43.63
Fixed Carbon (%)	34.37	48.75
Ash (%)	5.37	7.62
HHV (BTU/lb)	8,165	11,582
Ultimate analysis	As received	Dry basis
C	47.52	67.40
H	3.32	4.71
O	13.27	18.82
N	0.60	0.86
S	0.41	0.58
Cl	35 ppm	50 ppm
Ash	5.37	7.62
Total	100.00	100.00
Hg (µg/g dry coal)	N/A	0.08 ± 0.02
Hg (lb/TBTU)	7.17 ± 1.79	7.17 ± 1.79

Figure 2 shows the total mercury levels measured at the air heater inlet and the stack over the entire long-term demonstration period. The reported mercury levels are total gaseous mercury, i.e., both elemental and oxidized, corrected to 3% O_2 and reported in micrograms per dry standard cubic meter (µg/dscm). PS Analytical mercury systems were used for the measurements. For measurement at the air heater inlet, a solids-free flue gas was sampled by an inertial separation probe (ISP) in order to minimize solids-flue gas interaction during sampling.

For the first three days of the testing, mercury levels were measured at the air heater inlet and stack without operating the Mer-Cure™ system. This allowed re-establishment of the baseline mercury level before any long-term Mer-Clean™ sorbent injection. The baseline stack

level was 12.6 µg/dscm. The two mercury levels observed during these initial three-day period showed 11.6% native removal of mercury between air heater inlet and stack, in agreement with the previous baseline measurements.

The total mercury at the air heater inlet fluctuated widely between 8 µg/dscm and 25 µg/dscm and its average over the 32-day period was 14.9 µg/dscm. The long-term sorbent injection testing started with Mer-Clean™ 8 sorbent at 52 lb/h (or 0.94 lb/MMacf, where the "actual" condition refers to the actual stack condition, i.e., 335°F and 6.6% O_2,). Within an hour from the start of sorbent injection, the mercury level reached a steady state level of 0.75 µg/dscm, showing 95% removal of air heater inlet mercury (or 94% removal of baseline stack mercury). This test condition was maintained for 5 days.

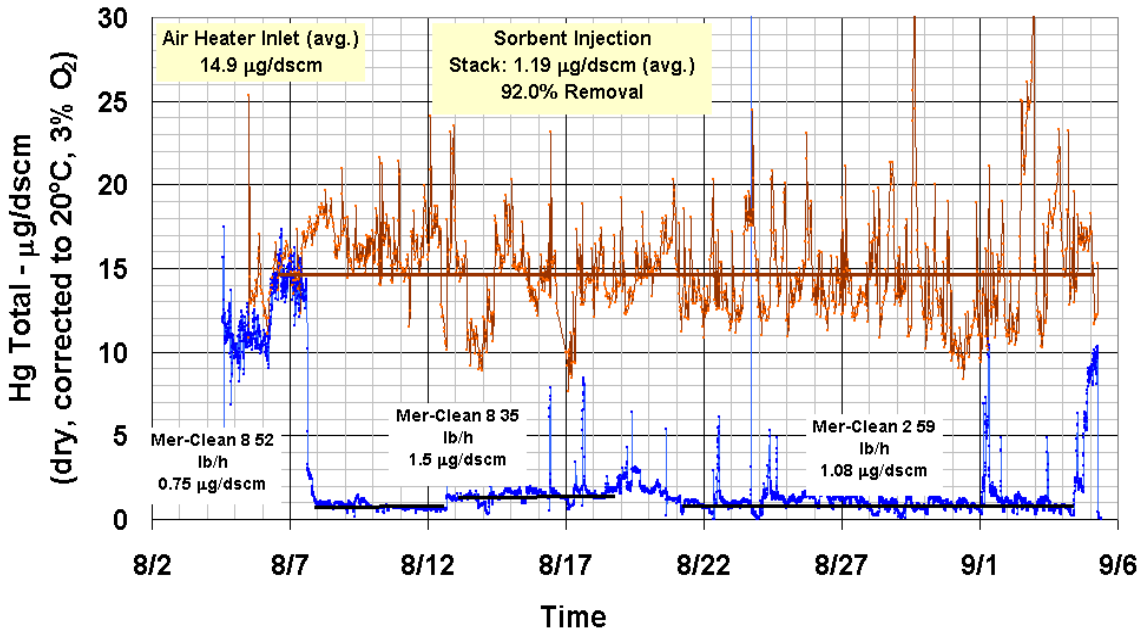

Figure 2. Total mercury levels at the air heater inlet and the stack for DJ3 during long-term testing

The sorbent injection rate was then decreased until 90% removal was achieved. At 35 lb/h (or 0.63 lb/MMacf), the steady state stack mercury level reached 1.5 µg/dscm giving 90% removal. Mer-Clean™ 2, a variation of Mer-Clean™ 8, was then used at 59 lb/h (1.06 lb/MMacf) for the rest of the test program to achieve 1.08 µg/dscm, or 93 % removal of air heater inlet mercury. The 30-day average stack mercury level with injection of Mer-Clean™ sorbents at various rates was 1.19 µg/dscm, giving 92 % removal of air heater inlet mercury, or 91% reduction of uncontrolled stack mercury.

Figure 3 shows six sets of Ontario Hydro data measured simultaneously at the air heater inlet and the stack over the long-term testing period. The Ontario Hydro measurements were made while sampling flue gas for 90 minutes.

The Ontario Hydro data thus obtained verifies the long-term performance of Mer-Cure™ system measured by CMMs and discussed above. The Ontario Hydro measurements at the air heater inlet varied from 10.8 μg/dscm to 16.2 μg/dscm, and those at the stack ranged from 0.75 μg/dscm to 1.0 μg/dscm. The mercury removal efficiency calculated based on the air heater inlet level was consistently between 92% and 95%.

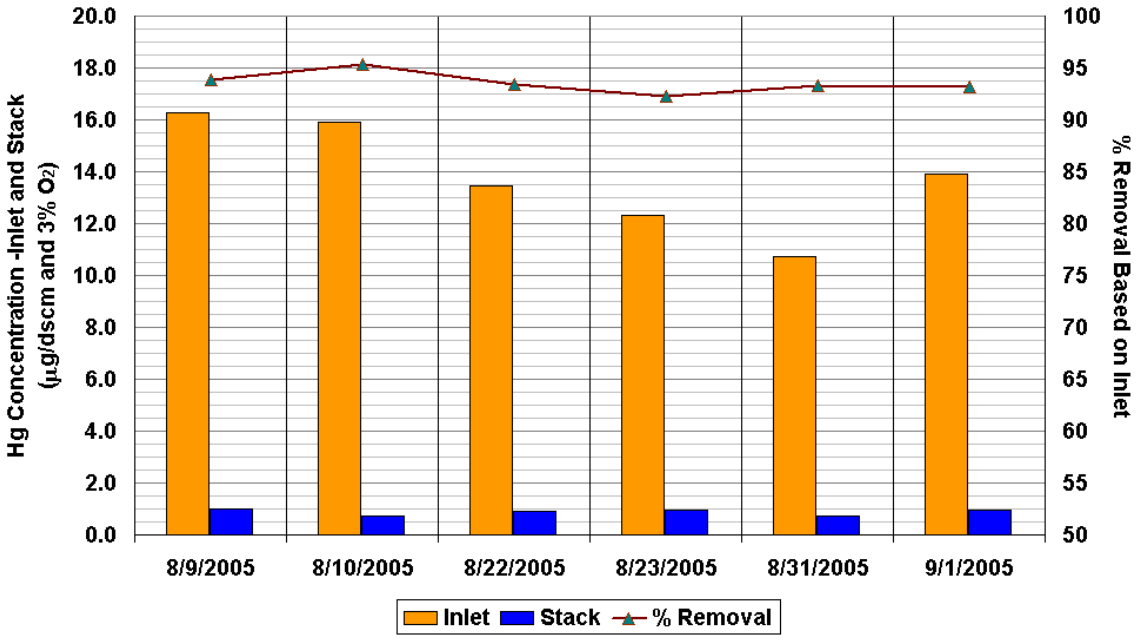

Figure 3. Performance of Mer-Cure™ system as measured by Ontario Hydro method

Figure 4 shows comparison between Ontario Hydro measurement data and CMM data. The CMM measurement at the stack shows consistently higher readings than Ontario Hydro measurement. On the other hand, the air heater inlet measurements do not show any such trend. The average absolute errors for the stack and the air heater inlet measurements are 24.8% and 9.2%, respectively.

Figure 5 shows comparison of mercury speciation between air heater inlet and stack as determined by Ontario Hydro measurements. At the air heater inlet, the percentage of oxidized mercury was only 5.3% and the rest was elemental mercury. (The air heater inlet temperature at DJ3 was around 770°F.) This is not surprising given that the PRB coal fired at DJ3 has only 50 ppm of chlorine, and no detectable amount of bromine.

In the presence of sorbent in the flue gas stream, about 65% of the mercury leaving the stack at DJ3 has been found to be in the oxidized form, a readily condensable form. Its practical implication for boilers equipped with scrubbers is that a scrubber in a boiler will further be able to remove most of this incoming oxidized mercury and potentially result in even higher mercury

reduction at the stack.

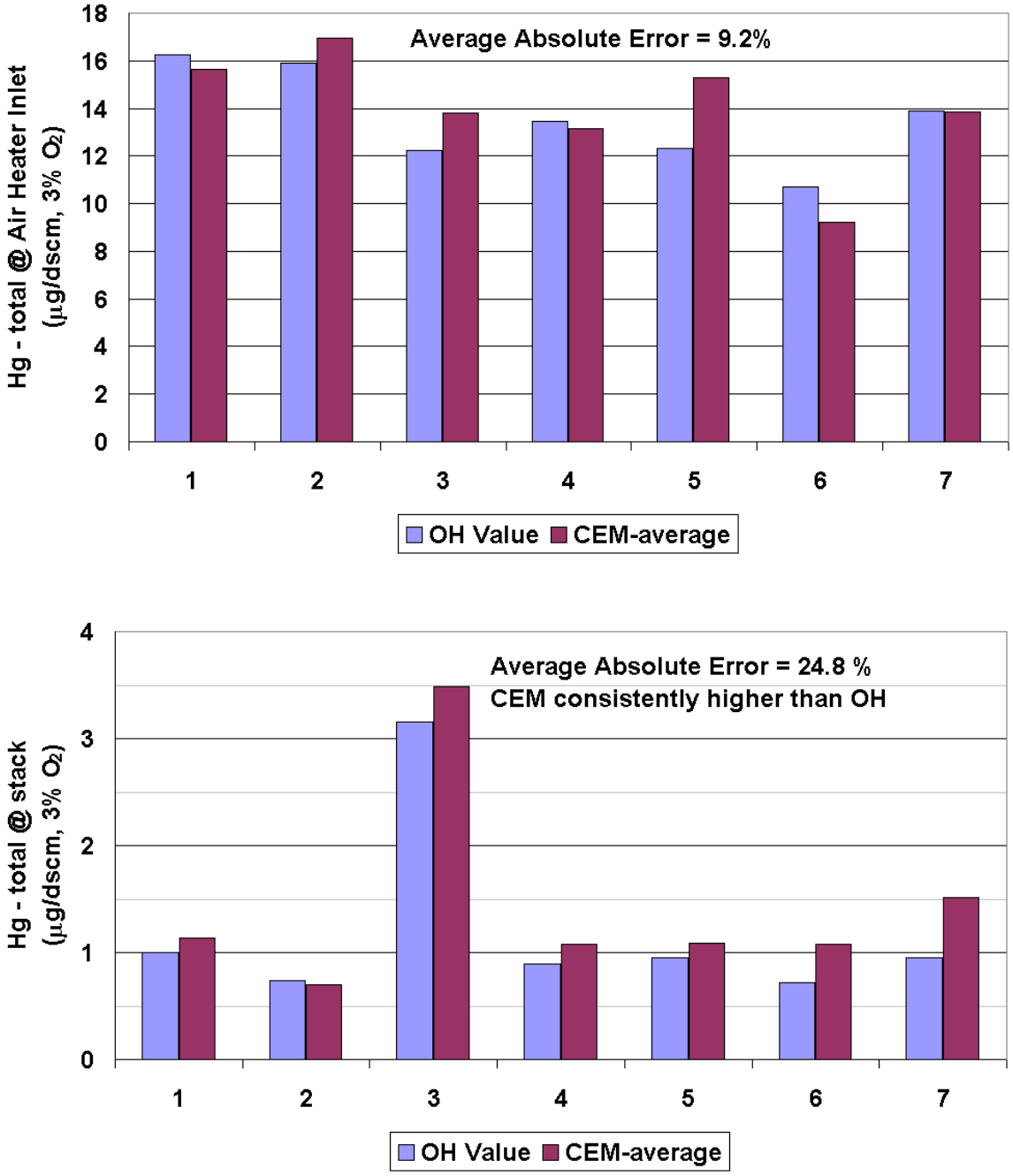

Figure 4. Comparison between Ontario Hydro and CMM measurements at DJ3

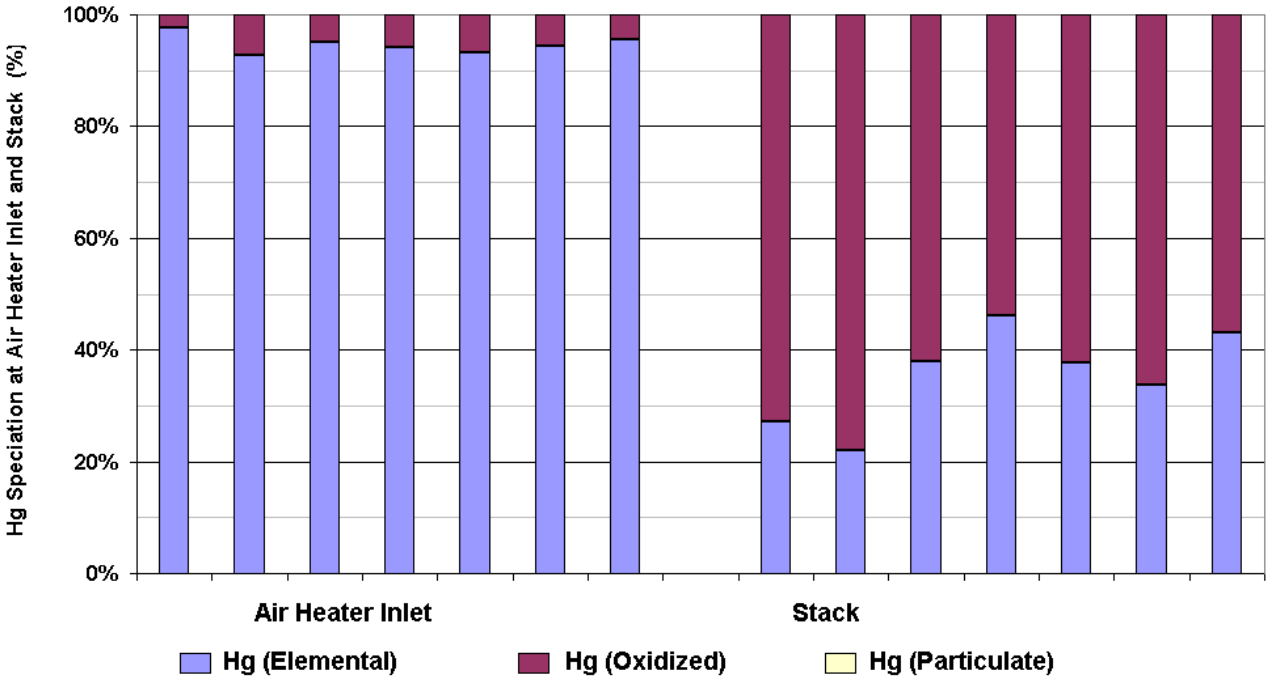

Figure 5. Mercury speciation at the air heater inlet and the stack at DJ3

Basin Electric's Leland Olds Station 1

Basin Electric testing has also been completed during this reporting period. Data reduction will be performed in the next reporting period. Selected preliminary data are presented in this report.

The Basin Electric testing at LOS1 started with a week of baseline mercury measurement. Figure 6 shows the baseline mercury levels from LOS1 at the ESP outlet. A Tekran mercury system was employed by EERC for the measurements. The reported concentrations are vapor phase mercury levels corrected to 68°F and 3% O_2. The average temperature and O_2 concentrations measured at the ESP outlet by EERC were 334°F and 5.2%, respectively.

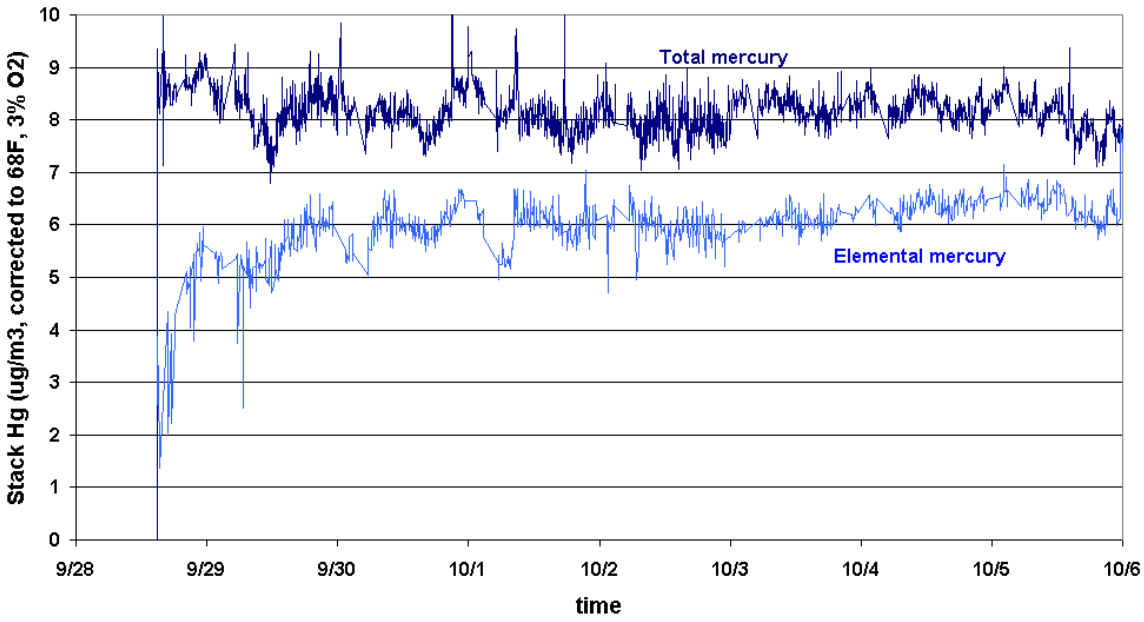

Figure 6. Baseline mercury measurement at Leland Olds Station 1

Some fluctuations in baseline levels were observed over time for both elemental and total mercury, which may be due to variation of mercury content in the coal fed. As shown in Figure 6, the total mercury varied between 7 μg/m^3 and 9 μg/m^3 during the baseline measurement period and averaged to be 7.3 μg/m^3, with a standard deviation of 0.9 μg/m^3. According to the CMM measurements, about 80% of the total gaseous mercury was in elemental form.

Figure 7 shows a typical response of the mercury levels from LOS1 when a Mer-Clean™ sorbent is injected to the backend of the boiler during parametric testing. Before injection, the total mercury level was 7.5 μg/m^3. At 10 am, 10/6, the Mer-Cure™ system was turned on and the Mer-Clean™ sorbent was injected at a constant rate. The mercury level decreased relatively

quickly from 7.5 g/m^3 to 3 μg/m^3 over half an hour period, followed by a slow decrease to 2.5 μg/m^3 over 4 hour period. Further increase in sorbent injection rate decreased the mercury level to approximately 0.8 μg/m^3, resulting in 90% removal of uncontrolled stack mercury.

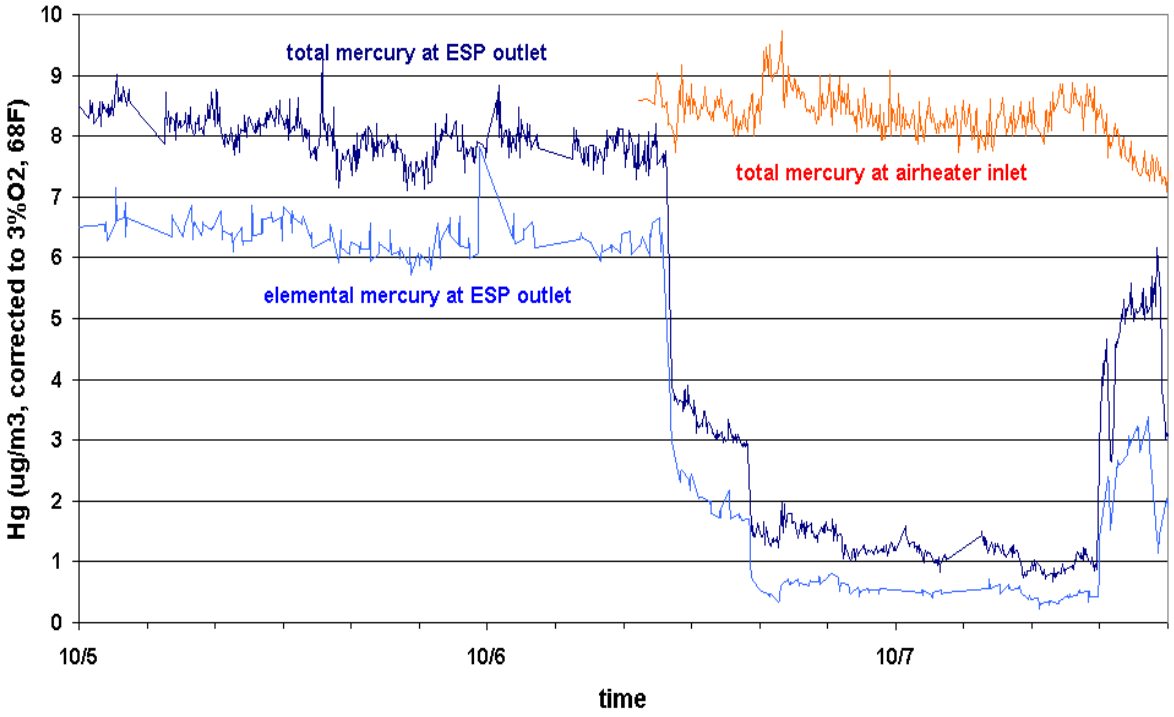

Figure 7. Typical response of ESP outlet mercury to Mer-Clean™ injection at LOS1

At 12 pm, 10/7, the Mer-Cure™ system was turned off, and the total mercury level at the ESP outlet recovered in two steps: initial immediate recovery over 30 minute period to 4 μg/m^3; subsequently, followed by a recovery at a slower rate. This recovery pattern has been observed for every test condition during parametric testing. In fact, this behavior has also been observed in previous testing conducted in our laboratory scale experiments, as well as in other field testing conducted in previous DOE-sponsored field demonstration programs.

The mercury speciation shows that without Mer-Clean™ injection, about 80% of the total mercury was in elemental form, whereas during injection, the elemental mercury level at the ESP outlet came down to less than 50% as observed at PacifiCorp's DJ3. This demonstrates the role of Mer-Clean™ in the flue gas duct on speciation of gaseous mercury.

Further analysis on the LOS1 data will be made during the next reporting period and reported in the next quarterly report.

CONCLUSION

Field demonstration of Mer-Cure™ system has been completed at PacifiCorp's DJ3 and Basin Electric's LOS1. Samples have been collected, and plant data have been obtained for both test campaigns. The long-term performance data from DJ3 have been analyzed and reported. Following are the summary of DJ3 test campaign:

- Long-term performance of Mer-Cure™ system at PacifiCorp's DJ3, as measured by both Ontario Hydro method and CMMs, shows that at injection rate of 0.63 lb/MMacf, 90% removal of total gaseous mercury has been achieved with Mer-Clean™ 8;
- Long-term performance data also show that while the air heater inlet mercury is mostly elemental mercury (95% of total mercury), only 35% of the stack mercury was elemental mercury during injection of sorbent. For boilers with scrubbers, most of this oxidized mercury will be removed, resulting in even higher removal efficiency.

Preliminary data from Basin Electric campaign also support the performance of Mer-Cure™ system in removing the gaseous mercury. The change of stack mercury speciation before, during, and after sorbent injection verify the role of Mer-Clean™ sorbent on mercury oxidation.

MILESTONES AND SCHEDULE

Both PacifiCorp and Basin Electric test campaigns have been completed as scheduled. Data reduction for PacifiCorp test campaign has been completed. Basin Electric test data are being analyzed. The next milestone of the program is completion and delivery of PacifiCorp site report in January 2006.

Also scheduled for the next reporting period is laboratory-scale testing of the Mer-Cure™ system while firing PacifiCorp and Basin Electric fuels.

Table 4. Schedule for Mer-Cure™ demonstration

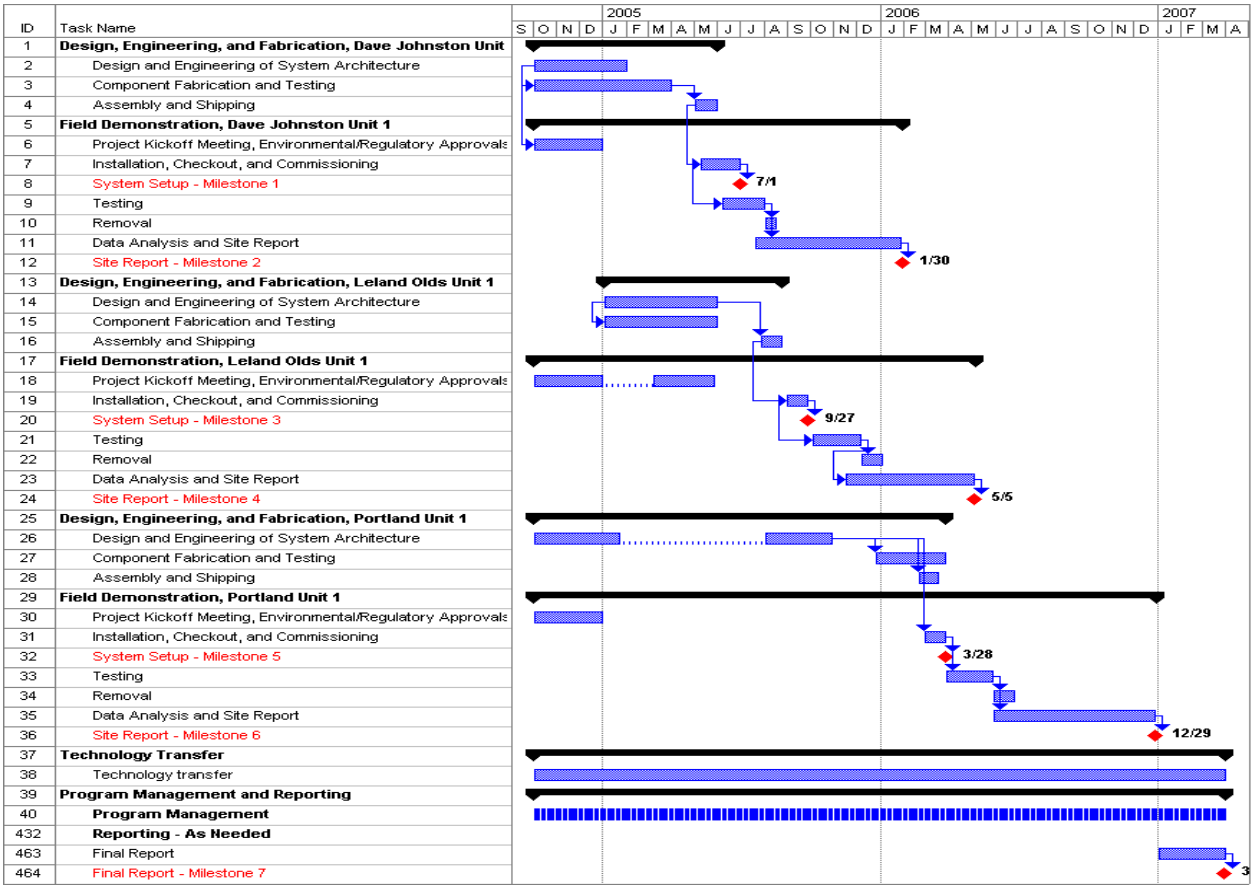

Table 5. Milestones and Deliverables

Milestone/ Deliverable	Original	Revised	Actual
1. System setup – Dave Johnston (PacifiCorp)	7/1/05		6/18/05
2. Site Report – Dave Johnston (PacifiCorp)	1/30/06		
3. System setup – Leland Olds (Basin Electric)	9/27/05		9/29/05
4. Site Report – Leland Olds (Basin Electric)	5/5/06		
5. System setup – Portland (Reliant)	3/28/06		
6. Site Report – Portland (Reliant)	12/29/06		
7. Final Report	3/30/07		